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Evoked Otoacoustic Emissions (EOAE's) and Inner Ear Damage from Navy Occupation Noise Exposure

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13. ABSTRACT (Maximum 200 words) In order to identify persons with early noise-induced cochlear damage and to predict susceptibility to future damage it is desirable to develop a test that is sensitive to effects of noise exposure on the auditory system. Traditionally, hearing has been monitored with behavioral methods requiring a threshold 10-15-dB shift to be considered significant. More recently otoacoustic emissions have been studied as a method, which may show earlier effects of noise exposure, and thus useful for hearing conservation programs. The aim of this project was to develop a test method applicable to the military population. Following a brief, intense noise, distortion product otoacoustic emissions (DPOAEs) were measured in normal hearing young adults for several conditions. Behavioral thresholds were measured using a Bekesy procedure. Experiment 1 involved a DPgram paradigm. F2 ranged from 1.0 to 4.0 kHz, with F2/F1=1.22. Stimulus levels were either L1=70 dB SPL, L2=60 dB SPL or L1= 65 dB SPL, L2=45 dB SPL. The exposure was a 100 dB SPL, 1/3 octave band of noise centered at 1.41. kHz. Results showed a consistent decrease in behavioral thresholds at 2.0 kHz immediately following exposure. Only one of ten subjects showed a consistent decrease in DPOAE amplitude for any F2 frequency. In a second series of experiments, DPOAE input-output functions were obtained for F2=4.0 kHz, with F2/F1=1.22 and L1=L2+15 dB, before and after exposure to a 100 dB SPL, 1/6-octave band noise centered 2.28 kHz. Pre-exposure I/O functions were very stable. In response to low to moderate level stimuli, DPOAE amplitude tended to decrease immediately post-exposure, increase and then decrease again (i.e., bounce). While for both DP paradigms the time course of the DPOAE amplitude shifts roughly paralleled threshold shifts, there was significantly inter-subject and intra-subject variability. Behavioral threshold shifts were consistently more robust than DPOAE changes

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Children's
Hospital & Regional Medical Center

August 28, 1998

Harold L. Hawkins, Ph.D.
Scientific Officer, Code 342PS
Office of Naval Research
Ballston Tower One, Room 817-11
800 North Quincy Street
Arlington, Virginia 22217-5660

Subject: **Final Technical Report**
Grant # N00014-94-1-0411
Title – "Evoked Otoacoustic Emissions (EOAE) and Inner-Ear Damage from Navy Occupational Noise Exposure"
Performance Period - 02-15-94 – 03-01-98

Dear Dr. Hawkins:

As requested by the Office of Naval Research, enclosed are three copies of the final technical report with the accompanying report documentation page (SF 298) for the above-referenced grant. I would like to thank you, on behalf of Children's Hospital and Regional Medical Center, for the opportunity to have been involved in this important research effort.

If any additional information is required, please contact Elizabeth Trias, Public Grants Coordinator, in our Research Administration Office. Her telephone number is (206) 526-2023 and her email address is etrias @chmc.org.

Sincerely,

Jeffrey Sconyers
Vice President & General Counsel

cc: Director, Naval Research Laboratory
Connie DuPuis, Grants Specialist, Seattle Regional Office, ONR
Defense Technical Information Center ✓ - 2 copies

Final Report

Evoked Otoacoustic Emissions (EOAEs) and Inner-Ear Damage from Navy Occupation Noise Exposure

15 February 1994 – 10 May 1997

Susan J. Norton

Children's Hospital & Regional Medical Center
Seattle, WA 98105

Subcontract from:

Lynne Marshall

Naval Submarine Medical Research Laboratory
Gorton, CT 06349

Introduction

This report summarizes services provided to Dr. Lynne Marshall as well as work done in our own laboratory between February, 1994 and May, 1997. This grant was originally submitted in January 1992. Absolutely no funds were received until 1995; however, Dr. Marshall was provided with and expected assistance beginning in 1993 – 1994.
My laboratory has been conducting research on the effects of brief intense sound exposures known to produce temporary threshold shifts (TTS) since 1986. We have measured the effects of intense sound exposure on psychophysical two-tone suppression and cubic difference tones (Norton and Mott, 1987). In addition, we have investigated the effects of intense sound exposure on spontaneous otoacoustic emissions (Norton, Mott and Champlin, 1989). We extended this paradigm to study the effects of prior and/or concurrent contralateral stimulation on the effects of intense sound exposure (Norton, Mott and Neely, 1989). Most recently, we have been investigating the effects of intense sound exposure on transient evoked otoacoustic emissions (Norton and Hayes, 1990; Hayes and Norton, 1991). This work has occurred in conjunction with our work on the relationships between evoking stimuli and the characteristics of evoked otoacoustic emissions in normal-hearing and hearing-impaired subjects.

The services we provided to Dr. Marshall and her laboratory included the following:

1. Software including source code to run experiments.

2. Circuit diagrams for construction of hardware to conduct experiments.

3. Experimental design.

4. Continuous telephone consulting with the staff at Gorton.

In addition, we conducted several pilot experiments on the effects of noise exposure on evoked otoacoustic emissions (EOAE). The initial hypothesis proposed in the grant application was that EOAEs would be a sensitive tool for monitoring the effects of intense noise exposure on navy personnel. As seen in the attached abstract of a paper presented at the Midwinter Meeting of the Association for Research in Otolaryngology in February 1997, our findings do not support this hypothesis.

Effects of Brief Exposure to Intense Sound on Distortion Product Otoacoustic Emissions

S.J. Norton, W.A. Harrison, K.E. Mascher, K.H. Franck

Children' Hospital & Regional Medical Center
Seattle, WA 98105

Poster Presented at the

Association for Research in Otolaryngology Midwinter Meeting

February 2-6, 1997

(Work Supported by the Office of Naval Research (SJN, WAH, KM) and NIH Training Grant T32-DC00033 (KF))

Abstract

In order to identify persons with early noise-induced cochlear damage and to predict susceptibility to future damage it is desirable to develop a test that is sensitive to effects of noise exposure on the auditory system. Traditionally, hearing has been monitored with behavioral methods which require a 10-15-dB shift in threshold to be considered significant. More recently otoacoustic emissions have been studied as a method, which may show earlier effects of noise exposure, and thus are useful for hearing conservation programs. The present work was undertaken with the aim of developing a test method applicable to the military population. Following a brief, intense noise, distortion product otoacoustic emissions (DPOAEs) were measured in normal hearing young adults for several conditions. Behavioral thresholds were measured using a Bekesy procedure. Experiment 1 involved a DPgram paradigm. F2 ranged from 1.0 to 4.0 kHz, with F2/F1=1.22. Stimulus levels were either L1=70 dB SPL, L2=60 dB SPL or L1= 65 dB SPL, L2=45 dB SPL. The exposure was a 100 dB SPL, 1/3 octave band of noise centered at 1.41. kHz. Results showed a consistent decrease in behavioral thresholds at 2.0 kHz immediately following exposure. Only one of ten subjects showed a consistent decrease in DPOAE amplitude for any F2 frequency. In a second series of experiments, DPOAE input-output functions were obtained for F2=4.0 kHz, with F2/F1=1.22 and L1=L2+15 dB, before and after exposure to a 100 dB SPL, 1/6-octave band noise centered 2.28 kHz. Pre-exposure I/O functions were very stable. In response to low to moderate level stimuli, DPOAE amplitude tended to decrease immediately post-exposure, increase and then decrease again (i.e., bounce). While for both DP paradigms the time course of the DPOAE amplitude shifts roughly paralleled threshold shifts, there was significantly inter-subject and intra-subject variability. Behavioral threshold shifts were consistently more robust than DPOAE changes. The results of these experiments indicate either that (1) we did not use appropriate paradigms to detect consistent, robust effects of TTS conditions on DPOAEs; or (2) DPOAEs are not consistently affected by TTS conditions. (Work supported by Office of Naval Research and NIH grant T32 DC00033.)

BACKGROUND

Exposure to intense sound can result in either temporary or permanent cochlear damage in both humans and animals. Traditionally hearing has been monitored with behavioral methods that require a 10-15-dB shift in threshold to be considered significant. Recently it has been suggested that evoked otoacoustic emissions may be more sensitive than behavioral thresholds to the early effects of noise exposure and thus, may be useful in hearing conservation programs.

The present work was undertaken with the goal of developing a test that would be more sensitive to the effects of noise exposure on the auditory system than behavioral threshold. The hypothesis was that such a test could identify individuals with early damage (i.e., before a behavioral threshold shift is detectable), and possibly predict susceptibility to future damage. Such a test would be very useful to organizations such as the military or industries in which workers are routinely exposed to high levels of noise.

METHODS

As a first step, we designed a classical behavioral temporary threshold shift (TTS) experiment with distortion product otoacoustic emissions (DPOAE) measurements interleaved.

We began with a relatively high-level exposure that would produce clear TTS. Once we found a clear effect on both behavioral thresholds and DPOAE, we planned to decrease the exposure level in order to assess the difference in sensitivity of the two measures.

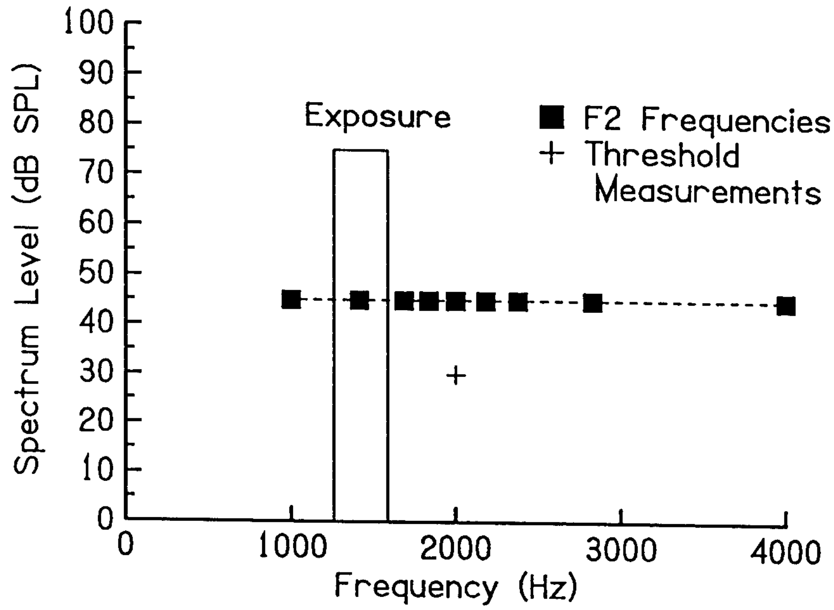
In Experiment 1, DPOAE amplitudes as a function of F2 frequency for a fixed L1 and L2 were measured, i.e., "DPGrams". F2 frequencies were in 1/8-octave steps above and below 2.0 kHz. The exposure was a 1/3-octave band of noise centered at 1.414 kHz that is ½ octave below 2.0 kHz. Two stimulus levels were evaluated: a relatively high level with L1=70 dB SPL, L2=60 dB SPL, and a low-level condition with L1=65 dB SPL L2=45 dB SPL.

DPOAE measurements were interleaved with Bekesy threshold measurements at 2.0 kHz. The procedures were timed such that both a DPGram and behavioral threshold were obtained in two minutes. There were two "pre-exposure" cycles, followed by either an 8-min. exposure at 100 dB SPL or silence. "Post-exposure" the cycle was repeated at 0,2,4,6,8, 14,16,20,24,32,36,40,42,44,46,48,50,54, and 64 min. post-exposure. Four sessions per primary level were obtained for each subject. The order of the DPOAE and threshold measurements alternated between sessions. Sessions were separated by no less than 24 hours.

All subjects had thresholds of 10 dB HL or better for audiometric frequencies from 250 Hz to 6000 Hz, normal tympanograms and normal acoustic reflex thresholds. All subjects had DPOAE over a wide frequency and amplitude range. However, we did not require that their DPOAE met a minimum SNR or amplitude criterion.

In Experiment 2, DPOAE amplitudes as a function of stimulus level for a fixed F1 and F2 were measured, i.e., input-output (I/O) or growth functions. Parameters were selected to enhance the likelihood of obtaining significant effect on DPOAE.

Experiment 1
Alternating Behavioral Thresholds & DPGram Measurements



DPGrams

- F2=1.0, 1.414, 1.681,1.834, 2.0, 2.181, 2.378, 2.828, 4.0 kHz
- F2/F1=1.22
- L1=70 dB SPL, L2=60 dB SPL
- L1=65 dB SPL, L2=45 dB SPL

Bekesy Threshold Measurements

- 2.0 kHz
- 250 ms (40 ms $\cos^2$ rise-fall)

Exposure

- 1/3 Octave Band Noise Centered at 1.414 kHz
- 100 dB SPL
- 8 Minutes

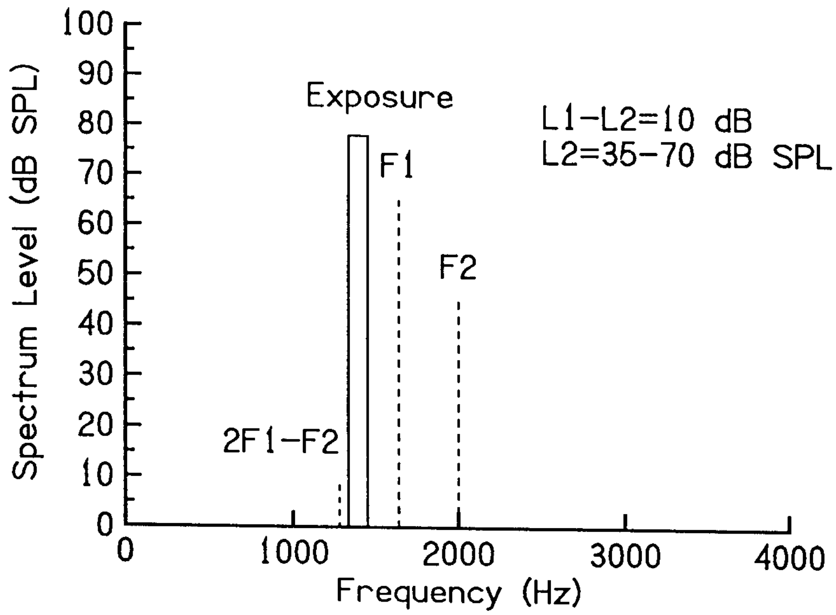
Subjects

- N=13 4 Males 9 Females Mean Age=27 years ($\pm$5)
- Normal Hearing, Negative Otologic & Noise Exposure History

Paradigm - 2 runs with no exposure 4 runs with exposure

Pre-Exposure	Exposure	Post-Exposure
DPG,Threshold		DPG,Threshold, DPG, Threshold...
Threshold, DPG		Threshold, DPG, Threshold, DPG....
4 min	8 min	64 min

Experiment 2
DPOAE Input-Output Functions



DPOAE Input-Output Functions

- F2=2.0 kHz
- F2/F1=1.22
- L1-L2 = 10 dB
- L2 = 70,65,60,55,50,45,40,35 dB SPL

Exposure

- 1/6 Octave Band Noise Centered at 1.414 kHz
- 100 dB SPL
- 8 Minutes

Subjects

- N=4   2 Males   2 Females   Mean Age=30 years ($\pm$ 3)
- Normal Hearing, Negative Otologic & Noise Exposure History

Paradigm - 4 runs with exposure

Pre-Exposure	Exposure	Post-Exposure
DP I/O Functions		DP I/O Function, DP I/O Function...
6 min	8 min	34 min

RESULTS

Figure 1 shows mean data across sessions and subjects.

- Behavioral threshold shifts were larger and more consistent than changes in DPOAE amplitude.
- DPOAE amplitude shifts and behavioral threshold shifts following noise exposure are not correlated (r^2=. 04 for L1=65 L2=45 dB SPL; r^2=0.1 for L1=70 L2=60 dB SPL).
- All but one subject showed a significant threshold increase immediately post-exposure ($F=6.737$, $p<.0001$). Differences between subjects were also significant ($F=9.049$, $p<.01$).
- For the low-level condition, L1=65 dB SPL L2=45 dB SPL, the difference between pre- and post-exposure DPOAE amplitudes at F2=1.414 kHz (i.e., on frequency) was not significant ($p=.4$). The difference was significant ($p<.05$) for F2=2.828 kHz (i.e., +1 octave). Consistent with previous work, the maximum post-exposure shift in DPOAE amplitude occurred for F2=2.0 kHz, ½ octave above the center frequency of the noise exposure ($p<.001$).
- For the high-level condition, L1=70 dB SPL L2=60 dB SPL, the only significant difference between pre- and post-exposures amplitudes occurred at F2=2.0 kHz ($p<.01$).

We failed to find a consistent and reliable effect on DPOAE amplitude post-exposure using an input-output function paradigm. The upper panel to the right shows data for one subject for one session. At very low stimulus levels the DPOAE becomes very erratic post-exposure.

The lower panel shows mean (across subjects and sessions) pre- and post-exposure DPOAE amplitude shifts for three stimulus levels on the I/O function. As can be seen there are no significant differences.

SUMMARY & CONCLUSIONS

The results of several different experimental paradigms were essentially the same - behavioral threshold shifts, even in untrained subjects, were both more robust and consistent than changes in DPOAE. These results were surprising. DPOAE at low to moderate stimulus levels are dependent upon normal outer hair cell function. Intense noise significantly affects outer hair cells. Furthermore, normal outer hair cell function is generally considered necessary for normal behavioral thresholds.

We have no ready explanation for these results.

- It is possible that the variability in DPOAE amplitudes across subjects made it difficult to see an effect. Because the goal of our work was to develop a more sensitive test of noise exposure using DPOAE the only restriction we placed on our subjects that they had DPOAE for F2 from 1.0 kHz to 4.0 kHz.
- We may not have used the optimal stimulus and response variables. In addition to the experiments reported here, we have looked in higher frequency regions (F2=4.0 kHz) and found the same results.

At this time, we must conclude that in young adults behavioral threshold shifts are the most reliable measure of TTS.

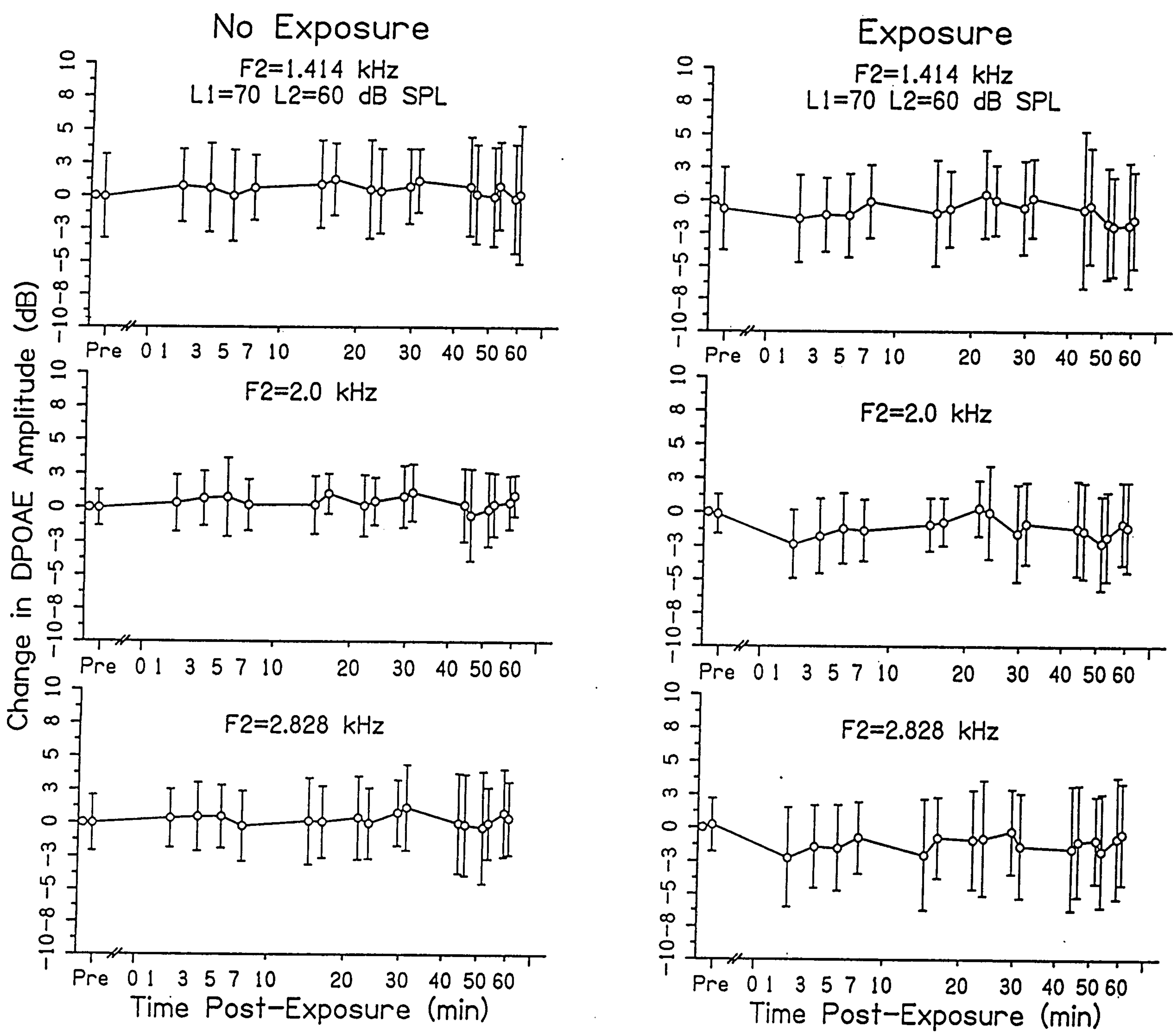

No Exposure
Exposure
F2=1.414 kHz
L1=70 L2=60 dB SPL
F2=2.0 kHz
F2=2.828 kHz
Change in DPOAE Amplitude (dB)
-10 -8 -5 -3 0 3 5 8 10
Pre 0 1 3 5 7 10 20 30 40 50 60
Time Post-Exposure (min)

Figure 1 (top)

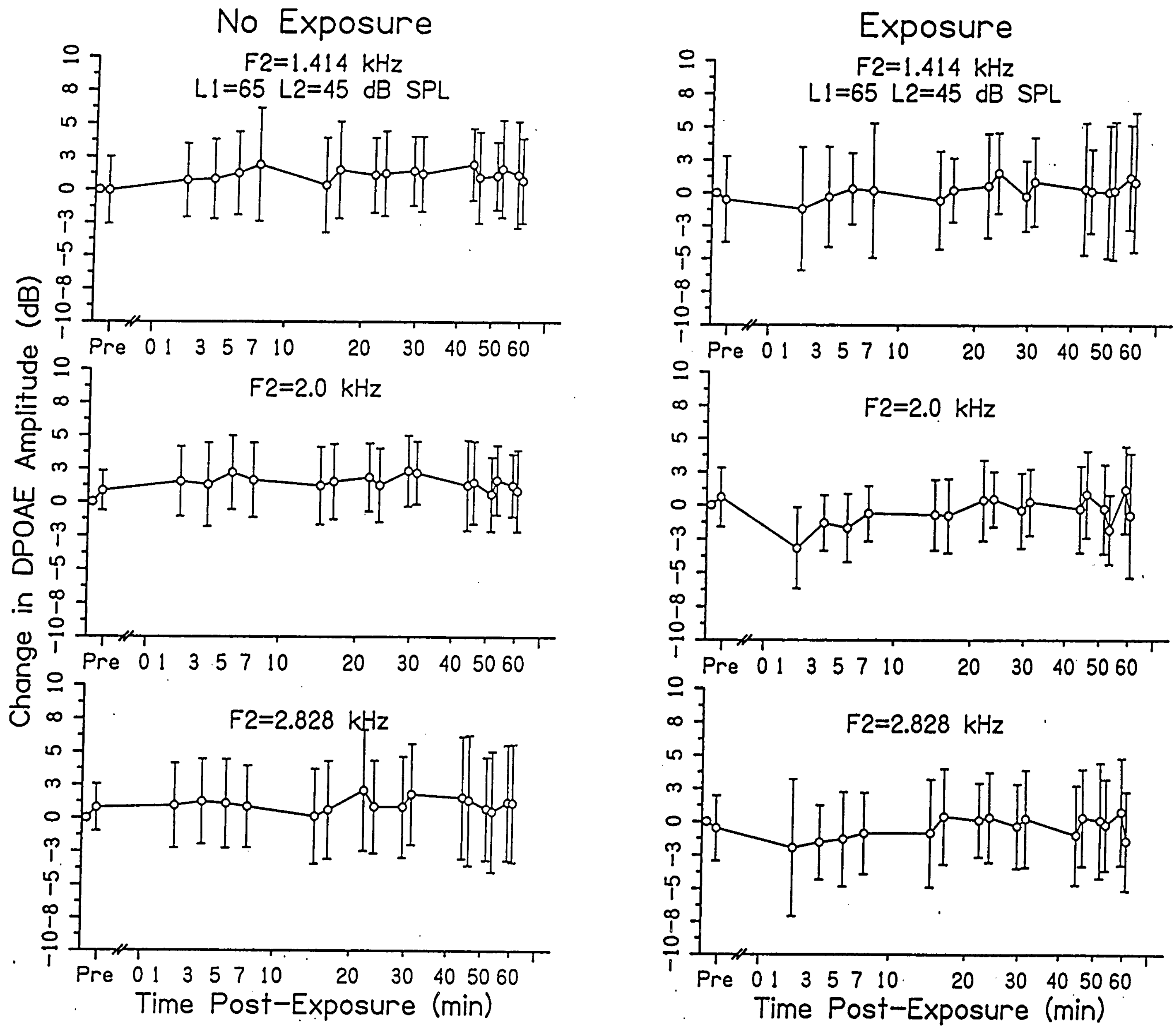


Figure 1 (middle)

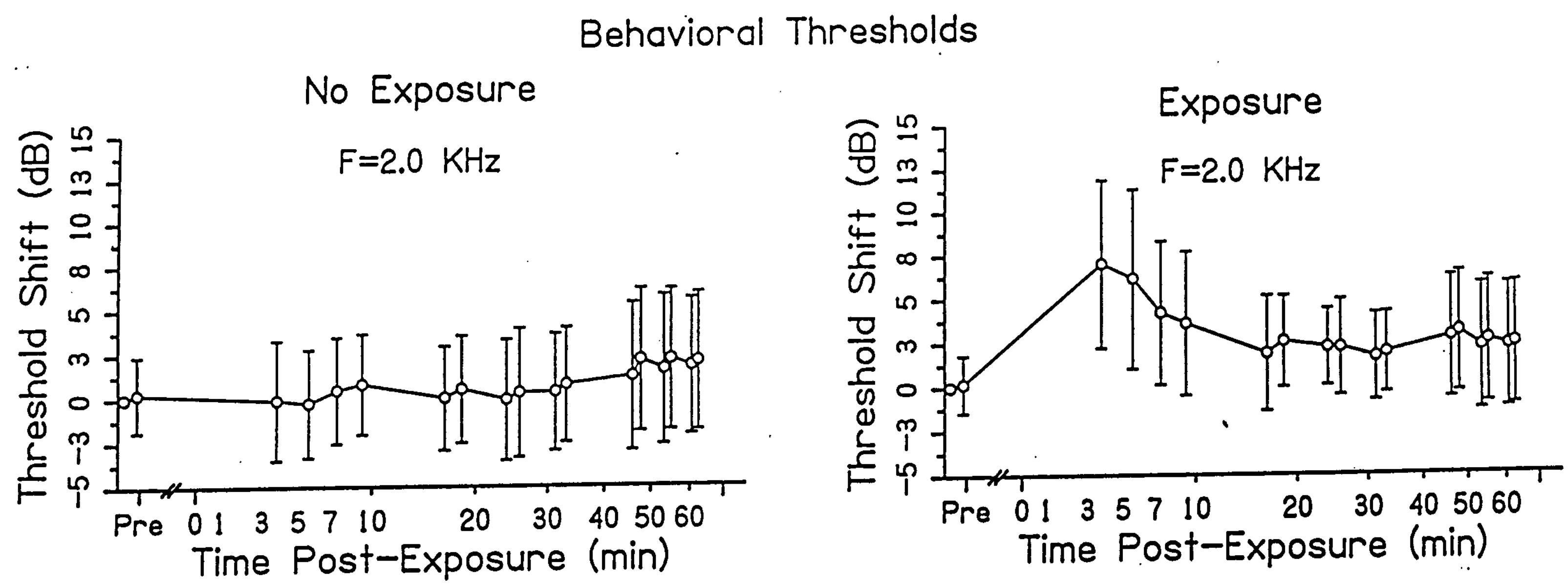


Figure 1 (bottom)

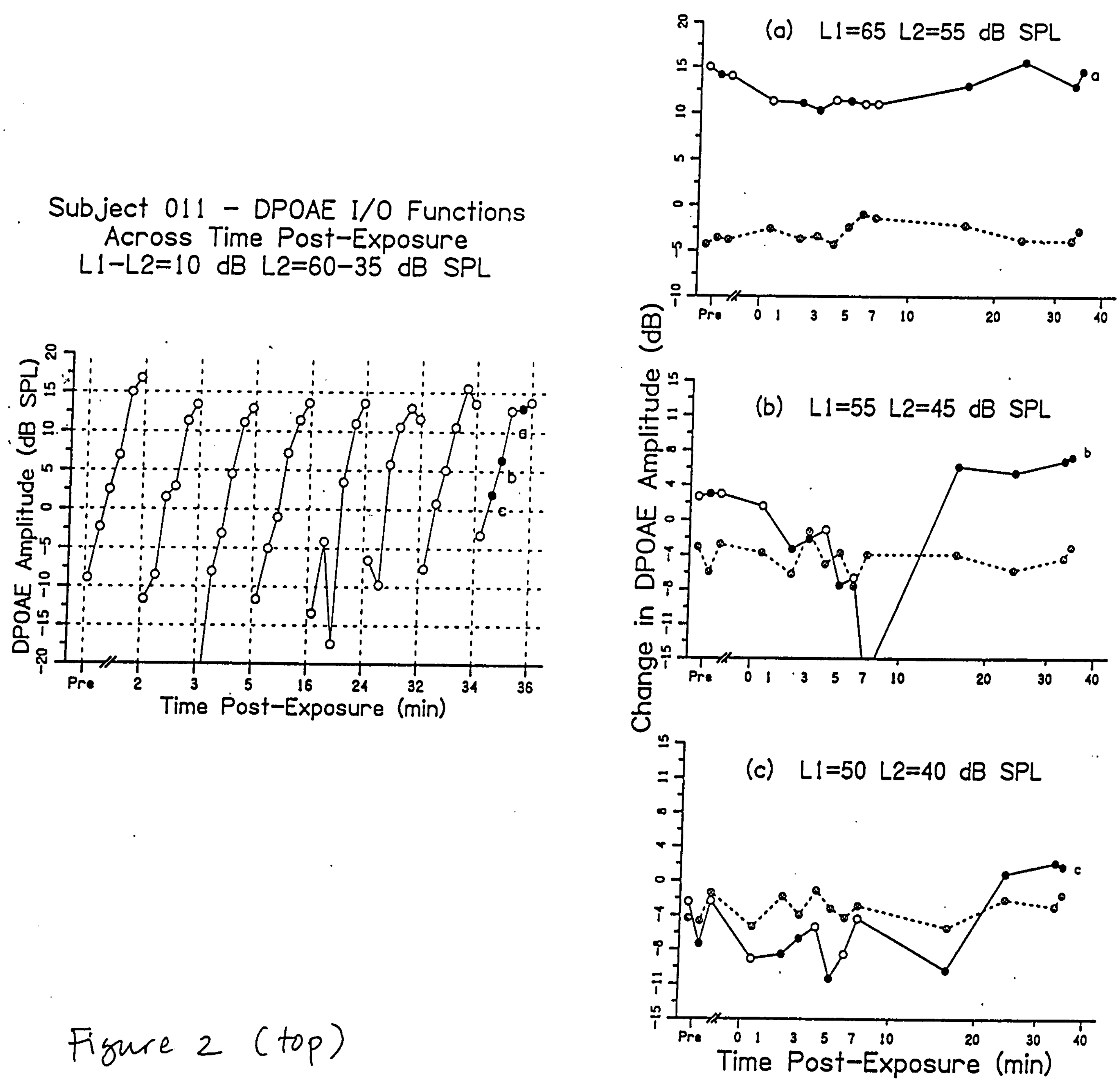

Subject 011 - DPOAE I/O Functions
Across Time Post-Exposure
L1-L2=10 dB L2=60-35 dB SPL
DPOAE Amplitude (dB SPL)
Time Post-Exposure (min)
a
b
c
Change in DPOAE Amplitude (dB)
(a) L1=65 L2=55 dB SPL
(b) L1=55 L2=45 dB SPL
(c) L1=50 L2=40 dB SPL
Time Post-Exposure (min)

Figure 2 (top)

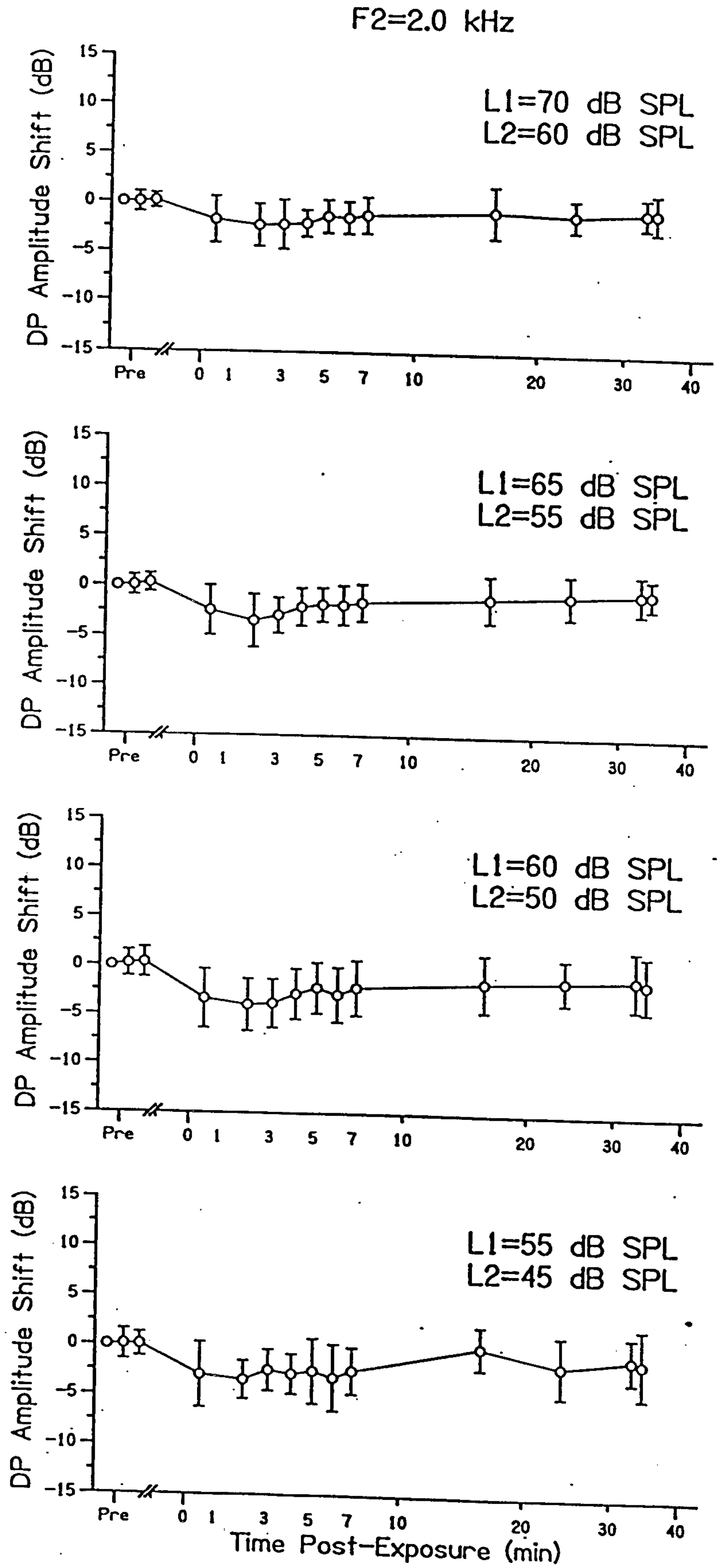


Figure 2 (bottom)